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Improvement of Computer Science Student’s Online Search by Metacognitive Instructions

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Abstract

The purpose of this study is to evaluate the improvement of computer science students' online searches by using metacognitive instructions. These instructions in the form of flowcharts with detailed descriptions help students to plan, monitor, and evaluate their actions when searching for scientific and technical information. The research methods include the analysis of existing applications of metacognitive instructions and conceptual models of search in the learning process. To carry out the experiment, we designed a tutorial that contains the described metacognitive instructions with a detailed search plan. During the experiment, students had the task of writing the review sections of their term or final papers using the tutorial. The results were evaluated based on the quality of the submitted reviews and tutor feedback. The students using metacognitive instructions significantly improved the quality of the review sections. The structure of review sections improved, and the analysis of sources became more rigorous with more precise keyword phrasing. The study confirms that the use of metacognitive instructions enhances information search and academic performance. The novelty of the study lies in the integration of the metacognitive approach with conceptual search models into the learning process of computer science students. The improvements can be adapted to other disciplines to expand the study to other academic areas and develop additional tools to support metacognitive learning.

Keywords:

Computer Science Students;
Metacognitive Scaffolding;
Online Search;
Metacognitive Instructions;
Scientific Search.

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1- Introduction

The rapid development of technologies, in particular the technologies of information search, has radically altered the approaches of students to information search when writing the papers. The main tools to search for information are internet search engines [1]. According to Dahlen & Hanson [2], students rely more on Internet sources than on libraries when writing the papers. A huge amount of data in the modern global network makes it highly time-consuming for students to search “bit by bit” for information relevant to writing a certain paper. To find the necessary information, there are many different sources that differ in the scope, the structure, and the quality of the content. In such conditions, students' ability to search and critically perceive the results of this search has become an important aspect of using online information [3].

Information search on the Internet has become routine and difficult to analyze [4]. This happens owing to the fact that the operation of search engines is becoming increasingly unclear to users. Commercial organizations control search engines, which makes the search process more difficult. Google has the largest share in the control [5], which currently processes approximately 83% of all queries worldwide [6]. A notable exception is Russia, where there is a large

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commercial search engine, Yandex. Yandex processes approximately half of the queries in the Russian segment of the internet [4]. This is due to the peculiarities of the Russian language which Yandex has been paying quite a lot of attention since its inception [7]. In addition, search engine algorithms are constantly evolving, and artificial intelligence has recently been applied in such algorithms [8], which makes it difficult to analyze the internal logic of such systems and predict search results.

On the other hand, the Internet is traditionally perceived as a useful source of information [2, 9, 10], even for teaching students, that provides a quick, easy, and effective source of information for a chosen topic when writing, e.g., a course project or a PhD paper [11]. At the same time, due to the poor structure and a huge number of search results, many users, including students, rely on simple heuristics to satisfy their information needs [12]. According to anonymous and face-to-face surveys with more than 500 respondents, many students mainly use search results in Yandex and Google [13] and rarely use other search engines. Despite the fact that students usually have great experience in information search on the Internet [14, 15] and consider themselves to be experts in the field, they are actually poor searchers because their poor search behavior strategies result in low search results [16]. Many studies of student search behavior have shown that inexperienced students follow common patterns, including [17]: lack of a clear search plan; use of Google only, hoping to obtain comprehensive search results; simple search heuristics; poor review of the obtained search results; and hasty conclusions. This search behavior can lead to health problems for students [18] because ineffective searches lead to uncertainty and take too much time. In addition, continuous sensory stimulation as part of intensive Internet use affects brain function broadly, including the ability to assess the current knowledge, which is critical for adaptive behavior and learning processes [19].

Zlatkin-Troitschanskaia et al. [17] show a lack of both research on the characteristics of online information and how these characteristics influence student learning in higher schools and how student learning can be facilitated by improving student information search strategies. Online search strategies are classified into behavioral, procedural, and metacognitive domains [20]. The behavioral and procedural domains describe the cognitive skills required for basic web-navigation including control, the trial-and-error method, etc. The metacognitive domain describes higher skills, including targeted planning, primary search goal selection, monitoring, and evaluation, which involve more complex forms of thinking and problem solving than cognitive strategies [21]. One way to improve information search strategies is to teach students metacognitive skills. These skills relate to metacognition, which is defined as knowledge about knowledge [22]. Metacognition allows students to plan, self-monitor, and self-evaluate their learning processes and results; therefore, it plays the key role in self-regulated search behavior. Developing such skills requires some assistance from teachers, smarter peers, or appropriate instruction [22, 23].

The recent research on metacognitive aspects of student search by eye tracking [24] revealed that these are the metacognitive skills that are most important for improving overall search effectiveness. It is expected that teaching students these skills will improve their metacognitive strategies and the search results will improve [25]. One of the effective ways to develop online search strategies is teaching metacognitive instructions to the students. Such instructions provide students with an initial structure that allows them to understand what they need to do to successfully achieve search results [26] as well as clear recommendations for self-control and regulation of their search behavior [27]. Using such instructions, students can improve their information search by monitoring their search behavior, comparing new knowledge with prior knowledge, and evaluating new material [28].

By now there is a great experience in using metacognitive instructions to improve student information searches on the Internet. The use of metacognitive instructions consolidates and develops student metacognitive abilities, especially the ones related to procedural knowledge, such as planning, search management, monitoring, and search result evaluation [29]. Previously, similar instructions had already been designed for secondary school students [30]. Experimental results showed that online queries made with its help were more integrated, efficient, continuous, metacognitive, and goal-oriented. Metacognitive instructions have been used for planning and monitoring Internet search processes for grouping and reorganizing information as well as tracking thought processes [31]. The experiment participants perceived the use of such a metacognitive instruction as more convenient, which contributed to obtaining a more pertinent search result. Thus, metacognitive instructions have shown effectiveness in improving the learning process. Meta-analyses [32, 33] showed that metacognitive instructions had a statistically significant impact on learning outcomes, with their widest use in the academic field, such as learning languages and literature.

Thus, student information search needs improvement, and metacognitive approaches have been shown to be an effective method for such improvement. However, the application of metacognitive scaffolding to improve computer science students' information search on the Internet has not yet been sufficiently studied. On the one hand, a large number of different empirical studies have been carried out on the effects of applying metacognitive instructions among high school and higher education students [25, 29, 31-36]. On the other hand, these studies cover various categories of learners without singling out computer science students. Therefore, gaps remain in the empirical validation of the metacognitive scaffolding application in the context of technical education.

In addition to empirical studies, there are the ones related to the use of conceptual search models to build metacognitive scaffoldings [28, 37]. These studies have repeatedly proved that conceptual models such as Kulthau's information search process [27] positively influence the formation of students' metacognitive abilities in the process of Internet search by facilitating planning, monitoring, and reflection. In particular, this influence has been demonstrated in studies of both guided and exploratory search [38, 39]. However, there is a lack of publications on metacognitive scaffoldings built on multiple conceptual models of search and customized for a specific application domain, as well as empirical research on the impact of such scaffoldings on student search.

Our study is aimed at filling this gap. The metacognitive instructions we propose are based on several formal conceptual models of search and customized for computer science students. The study hypothesizes that the use of such metacognitive instructions might be an effective approach to improve the efficiency of computer science student information searches as well as the quality of review sections in students' course projects and graduation papers. The study is an evaluation of the proposed hypothesis. We analyze the impact of the implemented metacognitive instructions on the student course project review sections, with the topics set individually. The posed questions for the research are:

- Would the metacognitive instructions improve the efficiency of computer science students online search for information?
- Would the metacognitive instructions improve the quality of students' scientific sources reviews?

2- Material and Methods

2-1- Basics for Metacognitive Instruction Design

Internet search for information, in particular search for scientific and technical information, has now become an integral stage of writing student course projects and the final qualifying papers. Besides, students are becoming the authors of scientific and technical publications, while the global network is the main supplier of information for writing such papers. At the same time, their success depends largely on the thoroughness of the selection and analysis of sources. In such a situation, it becomes relevant to design metacognitive instructions to search for information on a given topic. These instructions describe a student's search for scientific and technical information employing global network resources.

As the basis to design metacognitive instructions, we first consider conceptual models of the search. Much research has focused on online search and the conceptual models that describe it; particularly, a study by Xie [37] provides an overview of such models. The earliest of these is the relevance feedback model [40]. The disadvantage of this model is excessively simple interaction between a user and the system, with the information need being expressed in the form of a simple query with no consideration of the real interaction process between the system and the user. In addition, this model considers a user interaction with one search engine only, while current practice involves working with several systems at once.

The development of the traditional model is a level model of information retrieval interaction [41]. This model includes aspects of user involvement in the search process; that is, the information obtained from the system is combined with the user knowledge and applied to the current search situation. The episodic model of information retrieval interaction [42] assumes the repeatability of events (episodes) in the process of user interaction with the information found. The feedback model [43] assumes a cyclical nature of user interaction with search engines. Each cycle represents actions performed by a user between a query to the system and the further reformulation of the query. The conceptual model of polyrepresentation [44] takes into account many factors that influence the user and the search engine. The principle of intentional redundancy is the center of the model, according to which the documents found during repeated queries to the search engine have a higher chance of becoming useful to the user. The conceptual model of "actions" [45] proposed on the basis of research on information search behavior suggests that the user's search behavior depends on their emotional state.

The conceptual berry-picking model [46] describes user behavior as a random walk in the search space, which has two main characteristics. Firstly, the user information need itself keeps changing as a result of studying the search engine response to the query. Secondly, the user information needs are met not by a specific set of found documents, but on the contrary, by the entire set of links and documents at each stage of the changing search. This process is described through the analogy of picking berries in the forest. The berries are scattered throughout the bushes and are in no way connected with each other. The berries are divided into many types, with each corresponding to a separate query or a separate search topic.

The descriptive model of information problem solving while using the internet [47] has become widespread because it considers online search as a metacognitive process involving goal-directed planning, monitoring, and evaluation skills. According to the authors, these skills allow the subject of an online search to regulate their search activity, which has a significant impact on search results. The planned-situation interactive model of information search [37] focuses on how plans and situations determine the use of various information search strategies in the process of solving problems and achieving search goals. According to this model, planning and situational aspects determine choices and changes in information search strategies. The multidimensional model of user-web interaction [37, 48] focuses on the factors of the web environment that influence the user as well as the user's internal factors, such as emotional state and cognitive behavior.

In addition to the conceptual models of search, a number of studies have analyzed the metacognitive problems that students face when searching online and the metacognitive instructions that can help students solve these problems. In particular, in experiments with student metacognitive judgments in online search [24], it was found that some students experienced great difficulty in remembering the search process performed just a few minutes ago, which in its turn may motivate us to design metacognitive tools that would suggest storing the entire search history. The analysis of the problems that students encounter during metacognitive reflection can be solved by metacognitive instructions [49]. In particular, such assistance can be expressed in turning planning into explicit activity.

All of the conceptual search models discussed above are anyway based on practical studies of various search engines over different periods of time. Along with the common properties for all the above models, these models also have differences. In general, the considered models being vague do not promote their use in teaching computer science students. Such students got used to dealing with clear, sequential instructions in the form of flowcharts. At the same time, explicit instructions for online search can improve its effectiveness [50, 51]. Thus, it means that our metacognitive instructions should be quite explicitly formalized in the style of algorithm flowcharts.

2-2- Metacognitive instructions

The previous subsection makes us highlight the main properties of user interaction with search engines, which will form the basis to design the metacognitive instructions.

- According to the relevance feedback [40], the episodic [42], the descriptive [47], and the multidimensional [37, 48] models, the user remakes the query to satisfy his information needs, occasionally comprehending the information received from the system.
- In accordance with the level model [41], the polyrepresentation model [44], the planned-situational interactive model [37], and the berry-picking model [46], the information received from the system is combined with the user knowledge and implemented to the current search situation, thereby changing both the query and the information need.
- According to the feedback model [43], the user interaction with a search engine has a cyclic nature, and these cycles are nested within each other.
- In accordance with the polyrepresentation model [44], the documents users repeatedly face during the search process have a higher chance of becoming necessary to satisfy the information needs (the principle of intentional redundancy).
- According to the “actions” model [45], the search process consists of several successive stages where the user search behavior differs and is determined by the emotional state.
- In accordance with the berry-picking model [46], the user information need is satisfied by the entire set of web-links and documents at every stage of the search.

Along with these six properties, the following factors need to be taken into account when designing metacognitive instructions for online information search.

- The search engines are divided into universal and vertical ones [52], designed for searching on a specific topic. Accordingly, it is advisable to divide the search process, considering the instructions, into two stages: preliminary, carried out using universal search engines, and specialized, carried out using vertical search engines. Scientific search engines [53, 54], e.g., Google Academy and eLIBRARY, act as vertical systems for students.

- The Russian students need to search for scientific technical information at the present stage in both Russian and English, since English has de facto become the international language of scientific and technical communication [55]. Accordingly, metacognitive instructions should include the queries translated from Russian into English.
- Metacognitive instructions should have a level of formalization sufficient to ensure that students of computer science have a clear understanding of the sequence of specific actions that must be taken to achieve the search result in the form of satisfying the information needs.

As noted above, our metacognitive instructions will be quite explicitly formalized if they are presented in the form of flowcharts. In addition, this will allow the instructions to be integrated into an e-university system [56]. In accordance with the properties and described factors based on the existing conceptual models, the metacognitive instructions for writing student papers were designed. The instructions are formulated as two procedures, namely preliminary search in universal search engines and specialized search in vertical search engines, which are discussed below.

2-2-1- Procedure of information search in universal search engines

The input data for the procedure is a research topic for a course project, a graduation paper, or a thesis. A student is a performer of the procedure who uses several (usually two or three) universal search engines. The procedure consists of the following steps:

Step 1. Make up keywords on a given topic and translate them into English. Make a preliminary judgment about the correspondence of a set of keywords to the given topic.

Step 2. Make up a search plan as a list of questions on the given topic using the keywords and phrases obtained in the previous step. Make a judgment about the suitability of the search plan and set of keywords for the given topic. Based on this judgment, amend the search plan and rephrase the keywords if necessary.

Step 3. Send sequentially received keywords and phrases from the previous step to universal search engines and get results in the form of the first two pages of search results.

Step 4. Click each link and skim the opening web-pages. Assess the pertinence of the web-pages (its compliance to the information need [57]) by a five-point scale. Enter the obtained results into the search protocol in the form of a list with continuous numbering, with each item being a web-link to the search result with a brief description and notes containing some assessment of the pertinence of each assessed web-page.

Step 5. Analyze the most pertinent search results with a pertinence score of at least 4 and their descriptions from the resulting list for new keywords.

Step 6. Enlarge the search plan with the new keywords obtained from the previous step as well as with the related questions.

Step 7. Return to step 2 to supplement information needs and obtain search results for the new keywords. If there are no new keywords, then go to step 8.

Step 8. Using the most relevant search results, analyze the web-pages. The results of the analysis should be included in the protocol in the form of a text review of the web-pages. The pertinence of the obtained documents and their text reviews in the search protocol should be chosen as the documents closest to the given topic with access to their full-text versions, and save web-links to the copies in the search protocol.

The outputs of the described procedure are:

- Search protocol containing the initial and final versions of information needs and the keywords as well as the list of links to search results with continuous numbering;
- A brief overview of the most pertinent search results;
- Full-text versions of the most pertinent search results.

The described procedure is schematically depicted as a flowchart in Figure 1 and corresponds to the above six properties of user interaction with search engines and also takes into account the above three factors related to information search when writing student papers.

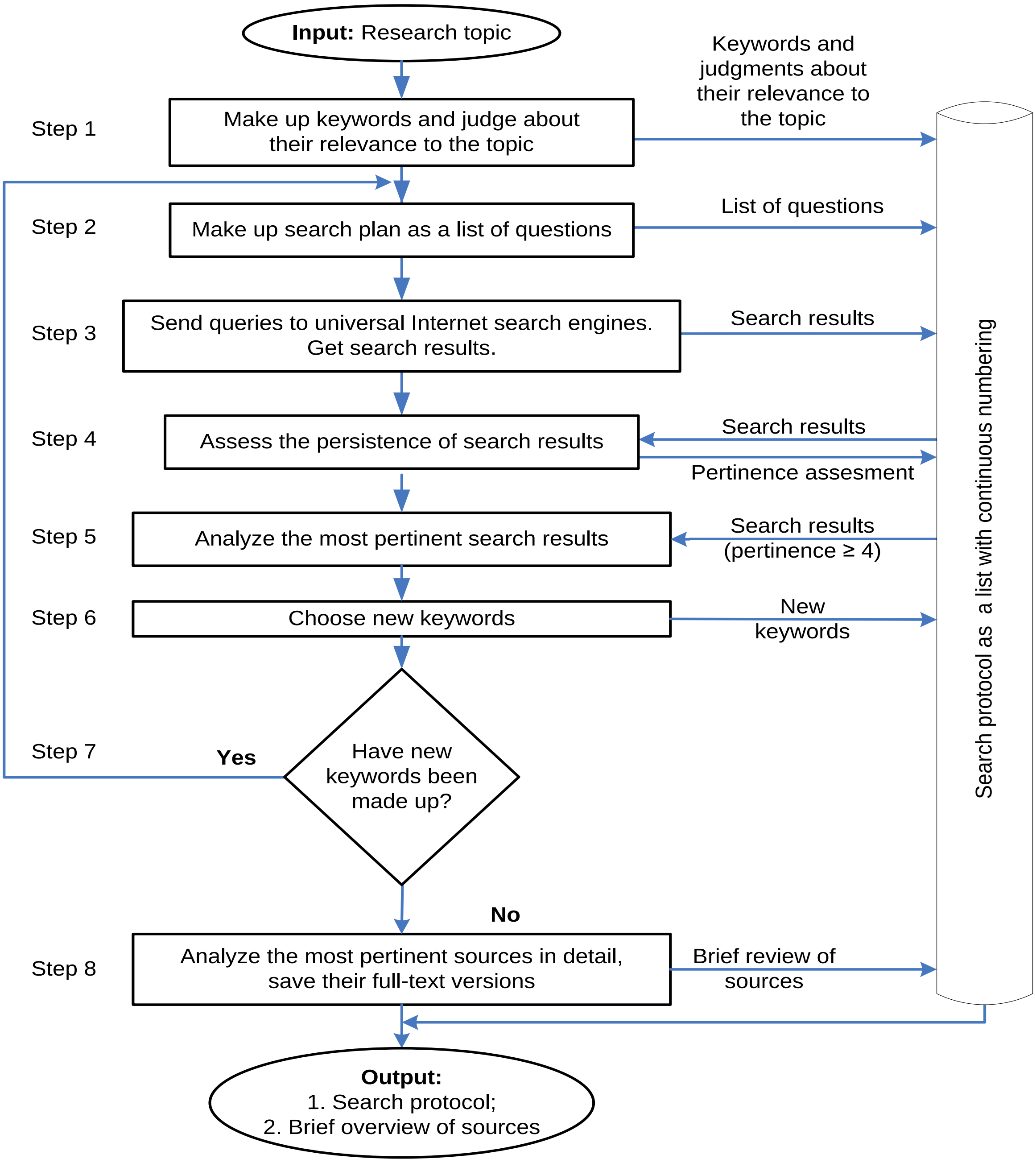


Figure 1. Procedure of information search in general search engines

All the obtained search results are saved into the search protocol that avoids data loss and helps ensure that the search trajectory (similar to the berry-picking model) covers a sufficient number of various web-pages directly or indirectly related to the given topic, which also corresponds to the principle of intentional redundancy.

2-2-2- Procedure of Information Search in Scientific Search Engines

The input data for the procedure for information search and analysis in scientific search systems is the output data of the previous procedure. This data is a list of keywords supplemented during the search in the universal search engines as well as the authors' names of the publications on the given topic. The performers of the procedure are students, but instead of universal systems they use several (usually two or three) scientific search engines. The procedure consists of the following steps:

Step 1. Analyze the search protocol and the summary of the obtained sources as a result of the previous procedure. Make an initial search plan for scientific search engines, including keywords, publications, and authors of publications related to the given topic.

Step 2. Make a judgment about the suitability of the search plan for scientific search engines and the set of keywords for the given topic. Based on the judgment, amend the search plan and rephrase the keywords if necessary.

Step 3. Get search results from scientific search engines by the search plan drawn up in the previous step. Assess the pertinence of the search results from scientific search engines.

Step 4. Make up new queries based on the results of the previous step.

Step 5. Return to step 1 to get search results for the new queries. If no new queries have been generated, go to step 6.

Step 6. Analyze the publications with the pertinence score 4 and higher. Choose the most pertinent publications and carry out a detailed analysis of them; if possible, obtain their full-text versions. Compile a review of sources with the preliminary stated task on the given topic.

The described procedure is schematically depicted in Figure 2. Steps 1 and 2 of the procedure are performed based on the results obtained from the previous procedure. Step 3 involves the preliminary review and evaluation of the search results, usually by reading the abstracts of the articles. In step 4, one can make up new queries, if necessary. Such a need may arise if a new term or a researcher's name on the chosen topic is revealed.

The associative method can be used to generate new queries. The method involves changing the query to semantically similar words from the same subject area – synonyms and quasi-synonyms. The use of larger groups of synonyms, quasi-synonyms, and related terms in the query makes it possible to compensate for some of the internal shortcomings of automatic indexing [58]. Despite possible information noise, associations can push students to a new way to solve the search problem, which is a formal method of stimulating creativity [59]. Step 5 checks the conditions for further actions. In step 6, the most pertinent publications are selected, which are then subjected to a detailed analysis.

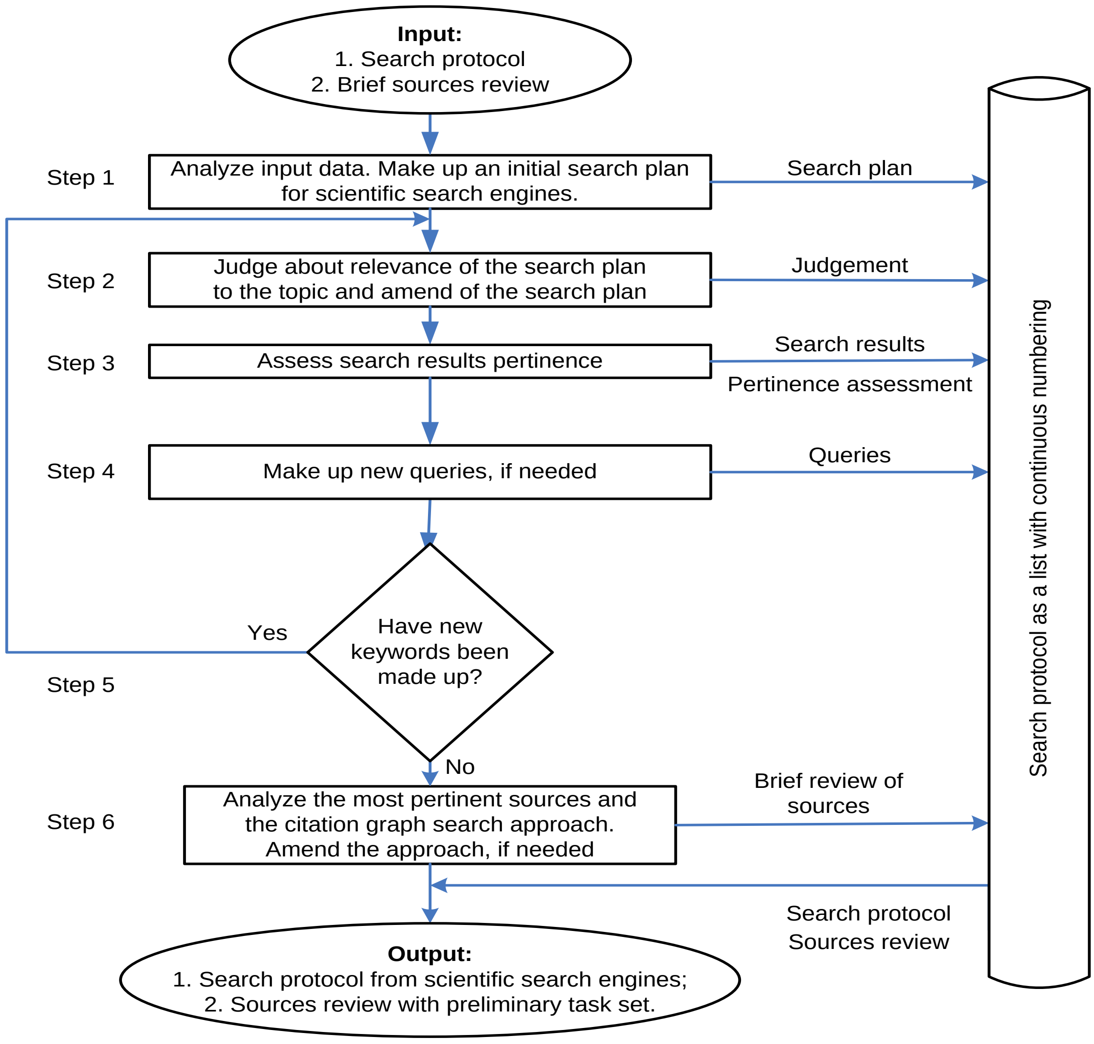


Figure 2. Procedure of information search in scientific search engines

For the detailed analysis, we use a citation graph, which is widely used to represent the citation range of the published scientific papers. It represents the connections between published works, such as citations and authorship [60]. It is known that citation graph search methods allow us to find documents that are not available when searching using keywords [61]. Moreover, the citation graph is crucial for better understanding of the content of scientific articles [62].

The citation graph (Figure 3) is a directed graph that shows the citation and reference structure of the research paper to other publications. The edges of the graph are directed from the considering research paper toward the ones that it refers to. To explain the publication impact to students through the analysis of the citation graph, we used the visualization proposed in Maguire et al. [63] together with continuous numbering of publications so that the number of each considered publication is unique. Figure 3 shows an example of a citation graph visualization, with the X axis – year of publication and the Y axis – number of citations for each considering publication. The considering publication is designated as K_1 according to its unique number in the reference list. The publication contains references to $K_1 - 1$ research papers published earlier than the one under analysis. Among these $K_1 - 1$ publications there are publications numbered 2 and 3 that belong to the same author as the analyzed research paper K_1, which is self-citation. The publication in focus is cited by $K_2 - K_1$ publications located to the right along the time axis. The figure indirectly shows the impact of the publication in focus.

The impact of the considered publication is the number of citations $K_2 - K_1$ as well as its number of references. Besides the number of references and citations in the publications, we should take into account the citation factors of the journal (the quartile, the impact factor, the international collaboration, etc.), the publishing agency; the author's h-index, the number of recent research papers and the years of publication, etc. [64]. The publication may not have many citations due to its recent issue, but it can be considered as having a high impact. Conversely, the publication may have many citing publications that belong to the same author (self-citation) that makes its impact weaker [65]. So, students should take it into consideration and design their metacognitive strategies more carefully.

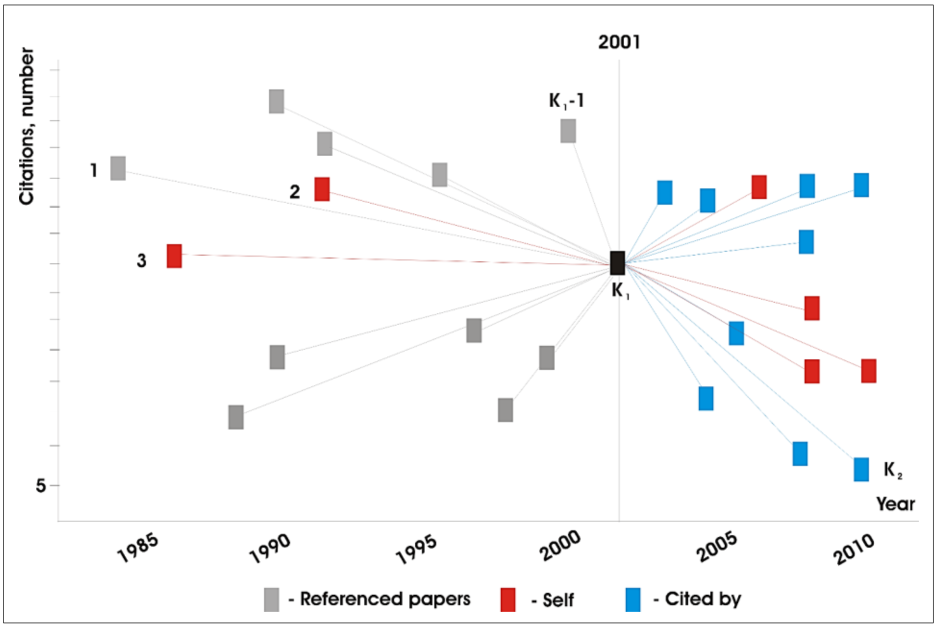


Figure 3. Visualization of publication impact

Many similar heuristic methods are used to analyze and visualize the citation graph [63, 66, 67]. In particular, it is offered to draw a judgement about both the impact of an individual publication and a collection of publications related to a certain researcher, an institution or a research area by the visualization shown in Figure 3.

We can distinguish two different strategies for searching by the citation graph. A continuous search implies the analysis of all vertices (publications) without exception, located at a distance of one arc from the analyzed vertex (publication). In a selective search, publications that appear to be the most important in the context of a given topic are analyzed. This importance can be indirectly assessed by the name as well as a part of the text preceding the citation. Student online search strategy usually falls between the two mentioned differences and has features of both. In our metacognitive instructions, we encourage students to describe and analyze the ways they do search by the citation graph.

3- Experiment

3-1- Criteria for the Effectiveness of Student Online Search

To answer the questions posed in the introduction, it is necessary to select the criteria for the effectiveness of student online search. Currently, search efficiency is assessed mainly by factors such as the time spent for the online search, the amount of data analyzed and the accuracy of the search result [68, 69]. The choice of specific criteria is determined by the analyzed aspects of the online search and its results. In particular, it is proposed that search efficiency criteria such as the number of queries, the number of processed search results and the amount of information should be included in the final report of the search results [70]. A search efficiency criterion is proposed to reflect the pertinence of the information found to improve subsequent search queries [71].

The above studies suggest a combination of qualitative and quantitative approaches to assessing the effectiveness of online search. It is noted that the criteria for the effectiveness of online search are determined on the one hand by the time spent on the search and on the other hand, by the thoroughness of this search [72].

Further, we will call non-normalized search efficiency criteria as search attributes. Since in our experiment the time for online search is fixed and the same for all the participants, we chose the following attributes: x_1 – number of viewed results; x_2 – number of search results with the highest pertinence; x_3 – number of queries; x_4 – number of search engine; x_5 – number of full-text documents among the results; x_6 – tutor's assessment of the student referencing reviews that shows their quality.

The values of $x_1, \dots, x_5$ can be obtained by the analysis of student online search reports. The values of x_6 are obtained by a ten-point scale given by the tutor for a review of the publications on the student search topics. Search performance criteria are obtained by the normalization of the corresponding attributes. There is no generally accepted procedure for normalizing attributes. The choice of the procedure is based on the fact that its use in sorting out practical problems allows one to obtain a positive result [73]. So, in our experiment we use a normalization procedure based on the Max-Min linear method [74]. The result of the normalization procedure will be criteria $y_1, \dots, y_6$.

To answer the first question posed in the introduction, we use a general criterion for the efficiency of student online search, which will be calculated as the average value of criteria $y_1 , \dots, y_5$, the same way as it is for the efficiency criteria, for example in Huang et al. [75].

To answer the second question, we use the average value of criterion y_6 obtained by normalization of grades given by the tutor for the student scientific sources reviews.

3-2- Description of the Experiment

The experiment with the proposed metacognitive search instructions was carried out with various groups of students with different academic level in computer science. To carry out the experiment, we designed a tutorial that contains the described metacognitive search instructions with a detailed plan according to the described procedures and some examples of search protocols. We divided the students into two groups with 25 students at each academic level: bachelor degree (BSc) students, master degree (MSc) students, and (PhD) students. All the students were previously assigned individual topics for writing the final qualifying papers under the tutor guidance. At each academic level, five tutors were assigned to 50 students and for each tutor students were randomly distributed from groups 1 and 2.

The first groups of each academic level searched for information without the tutorial but based on their own ideas about the search, while the second groups searched for information on the Internet in accordance with the developed conceptual model considered in the tutorial. The second groups attended a lecture on the application of the designed tutorial based on metacognitive instructions. During the experiment, we obtained the criteria values $y_1^1,\dots, y_6^1,\dots, y_1^{50},\dots, y_6^{50}$ for each of 50 students included in both groups of each academic level. To bring them to a unit scale, these values were normalized by the Max-Min method [74], where the maximum results were taken as unit marks on the corresponding scales: $\max(x_1^1, \dots, x_1^{50}), \dots, \max(x_6^1, \dots, x_6^{50})$. The obtained values were averaged over the groups. For the first group of students at each academic level, the average values of the criteria were obtained in accordance with the expression:

$$y_k^1 = \frac{\sum_{n=1}^{25} x_k^n}{25 \max(x_k^1, \dots, x_k^{50})} \tag{1}$$

where y_k^1 – average value of the k[th] criterion for the first groups, $k = 1, \dots, 5$. For the second group of students at each academic level, the average values of the criteria were obtained in accordance with the expression:

$$y_k^2 = \frac{\sum_{n=26}^{50} x_k^n}{25 \max(x_k^1, \dots, x_k^{50})} \tag{2}$$

where y_k^1– average value of the k[th] criterion for the second groups, $k = 1, \dots, 5$. The generalized search efficiency indicator was calculated as the arithmetic mean of the average values of the criteria:

$$y_7^p = \frac{\sum_{k=1}^{5} y_k^p}{5} \tag{3}$$

where p – the group index, $p \in \{1,2\}$.

4- Results and Discussion

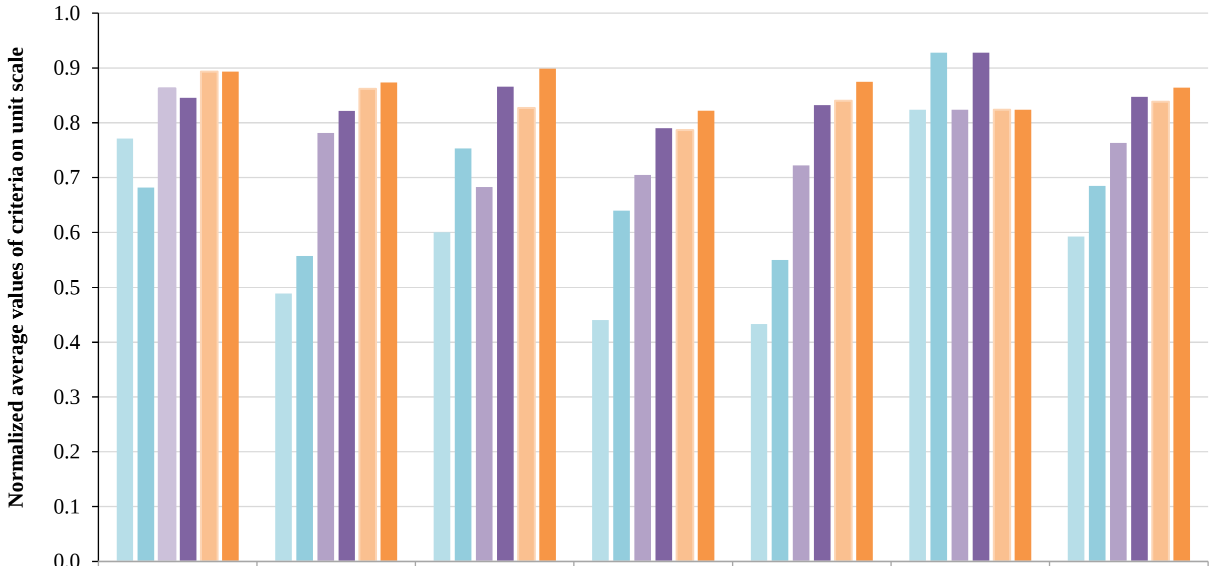
The online information search results obtained by both groups at each academic level were stored as reports. The report asked students to make up the queries and the search protocol as a list of viewed results with continuous numbering, including web-links, assessment of the pertinence of the web-links with a brief description as well as a brief overview of the search and the review section.

Figure 4 shows the results of the experiment as a diagram. BSc students of group 2 compared to group 1 viewed slightly fewer search results. This can be explained by the need to return to the tutorial to correctly follow the instructions given. This led to a 10% smaller number of sources viewed compared to group 1. At the same time, BSc students of group 2 identified 12% greater number of sources with the highest pertinence than group 1. This can be explained by the fact that BSc students of group 2 used 35% more search engines, including scientific search engines, compared to group 1. This, in turn, led to the fact that BSc students in group 2 found 44% more full-text sources compared to group 1.

Similar results of the experiment were observed among MSc students of groups 1 and 2. Given the larger number of views among MSc students compared to BSc students, the difference in the number of sources viewed between groups 1 and 2 decreased and amounted to 2%. This can be explained by higher level of general competence of MSc students in individual topics and higher online search skills. This is also confirmed by 24% greater number of full-text documents in groups 1 and 2 of MSc students than in BSc students, respectively (57% – group 1, 33% – group 2).

Students from group 2 of all academic levels made a larger number of queries compared to students from Group 1 (BSc students – by 26%, MSc students – by 15%, PhD students – by 5%). This can be explained by the fact that the tutorial explicitly indicates the use of the associative method, in which larger groups of synonyms and related terms are used to form queries.

The number of full-text documents found (y_5) is directly related to the quantity and quality of search engines used. Thus, BSc and MSc students of group 1, who consider themselves experienced in online search are characterized by poor search behavior strategies and the absence of a clear search plan. This resulted in a low search result compared to groups 2 of BSc and MSc students by 45% and 13% respectively. It should be noted that the difference in the number of full-text documents found among MSc students of groups 1 and 2 was only 4%.



	y1 search results viewed, number	y2 high pertinent sources, number	y3 queries, number	y4 search engines, number	y5 full-text sources, number	y6 tutors' assessment of review sections	y7 generelized search efficiency indicator
Bsc gr 1	0.771	0.489	0.600	0.440	0.433	0.824	0.593
BSc gr 2	0.682	0.557	0.753	0.640	0.550	0.928	0.685
MSc gr 1	0.863	0.782	0.683	0.705	0.723	0.824	0.763
MSc gr 2	0.846	0.822	0.866	0.790	0.832	0.928	0.847
PhD gr 1	0.893	0.862	0.827	0.787	0.840	0.824	0.839
PhD gr 2	0.893	0.874	0.899	0.822	0.875	0.824	0.864

Bsc gr 1 BSc gr 2 MSc gr 1 MSc gr 2 PhD gr 1 PhD gr 2

Figure 4. Average values of criteria by groups

The decrease in this difference among students with increasing academic levels can be explained by an improvement in students' information retrieval strategies due to their deeper mastery of metacognitive skills.

It is known that metacognitive skills are often underdeveloped in undergraduate students (e.g., first years of university study) [76]. In addition, empirical studies have shown that older students tend to demonstrate stronger metacognitive abilities, including the ability to plan and process complex information due to the cumulative effect of learning [29, 77, 78].

This emphasizes the importance of adapting metacognitive approaches depending on the age and educational characteristics of students. Such adaptation can be realized, for example by augmenting metacognitive instructions with new AI-technologies. Nowadays, there are several tools implemented on the basis of these technologies, in particular chat-GPT [79], scientific search system SciSpace [80] and others. These and similar tools can significantly improve the efficiency of information search and they can be integrated into metacognitive instructions using, for example the recently proposed methodology to do AI-assisted search for articles [81]. Certainly, in such adaptation, metacognitive instruction should take into account the students' level of knowledge and include examples of learning tasks appropriate to that level.

We have thoroughly studied a long list of scientific articles that consistently support the efficiency of metacognitive instructions for improving online information search skills, but no studies directly address the adaptation of metacognitive instructions to the specific needs of technical disciplines and humanities. However, universally applicable metacognitive instructions do not account for differences in approaches specific to computer science (e.g., algorithmic approach) and humanities (e.g., interpretive, qualitative approach). Our study attempts to adapt metacognitive instructions for their use by computer science students. This adaptation is based on the use of flowcharts with a clear sequence of actions, which corresponds to the thinking of computer science students [82, 83].

Definitions of information search efficiency vary widely across studies [25]. Criteria of search efficiency differ depending on a certain search task [50, 70]. These differences create problems in interpreting experimental results. In addition, empirical results of the use of metacognitive instructions differ across countries [33]. In our study, the search efficiency criteria reflect several aspects of information search by computer science students in Russia. In particular, the solution of the search problem as such is reflected in the following criteria: the number of viewed results – y_1, the number of queries – y_3, the number of search engines involved – y_4. In addition to the local criteria, our study introduces a generalized indicator of student search efficiency that summarizes all the local criteria. According to this indicator, we can judge the overall impact of methocognitive instructions application on the student search process.

The tutorial with metacognitive instructions caused an increase in all the assessed criteria. At the same time, the greatest growth was observed for criteria: y_4– number of search engines, y_3– number of queries made to the search engine as well as y_5 – number of full-text documents. However, criteria y_1 – number of viewed results and especially y_2 did not show a significant growth. The proposed generalized indicator of the tutorial effectiveness for BSc students showed 20% increase. It is obvious that the tutorial effectiveness decreases with the increase of students' academic level and amounts to 8% for MSc students and 3% for PhD students.

From the analysis of the grades given by tutors for the review sections, it becomes clear that BSc students in group 2 have more positive grades by 17% than in group 1. For MSc students this difference is 20%, while for PhD students it is 3%, which may be attributed to better metacognitive online search and research skills than MSc and BSc students.

The discussion of the search process with BSc students of group 1 mainly revealed that much of the search was based on a trial-and-error strategy, focusing on the usability of the sources rather than on their authority and reliability. This is confirmed by the set of search engines involved (mainly Google and Yandex, a small number of specialized systems). The search in such systems produces many irrelevant results, including advert, and returns little scientific content. Many students of groups 1 quickly lost patience and were unable to clearly define the boundaries of the search topic or find peer-reviewed articles on the topic especially fundamental studies. In addition, students in this group encountered difficulties in identifying and posing their information needs.

The discussion of the search process with BSc students of group 2 mainly revealed that, when searching, students regulated themselves by explaining how they monitor their search, what their information needs are, what keywords and search engines they choose, how they amend the queries, etc. The range of search engines expanded comparing to group 1. This can be explained by the search examples in the tutorial. Several students noted that the search examples encouraged them to apply the knowledge that they had already had but had not used. Those students of group 2 who gave their comments and communicated with the tutors achieved greater search results for the parameters assessed in the experiment.

However, some students of both groups encountered difficulties in comprehending the information found, also they are not aware of the experience gained in the search process. At the same time, in group 2 there were more students who found peer-reviewed authoritative sources on the topic. It starts at school when future students use the Internet to search for additional educational information [84], so they consider themselves experienced online searchers. Despite this, their search strategies are not perfect. This is especially true for scientific search and the use of scientific search systems, including the search by citation graph [64], which was confirmed by the results of our experiment.

The solutions of complex search tasks by students are largely determined by their motivation and their diverse cognitive styles [15, 29, 85, 86]. Metacognitive skills play an important role, namely the ability to regulate the search activity by justified planning and amend search behavior as well as the ability to modify the information need based on the analysis of search results, focusing on the most pertinent ones. Our study as well as many other [31, 32, 49, 50] show that lack of the regulation of search activity and unawareness of it decrease online search efficiency. At the same time, external regulators like metacognitive instructions can improve the efficiency of online search [25]. The metacognitive instructions we proposed are presented in the form of flowcharts with the description at each step that ensures their clear perception by computer science students.

Metacognitive instructions improve the search in other areas such as customer decision making in the hospitality industry [87]. Integration of visualization means of virtual reality into metacognitive instructions [88, 89] would be of great interest as well as some tools to analyze and visualize a large citation graph [64] in accordance with the interests of the user.

The weakness of the study is the difference in the search topics given to the students. Some topics are poorly researched and there is little information on them, so the search does not return a sufficient number of pertinent results.

Nevertheless, the results of our study show that the use of metacognitive instructions significantly improves the quality of information search and writing review sections by students. The obtained results and are consistent with previous studies in this area. Past studies [32, 33] show that metacognitive instructions significantly effect on learning outcomes, especially in areas such as language and literature learning. However, these studies did not emphasize the specificity of online information search in computer science, which makes the current study more relevant and specific.

In addition, previous studies [17, 25] note that students experience difficulty in identifying their information needs and using reliable sources. The present study found that students using metacognitive instructions were more likely to explain their actions and use a wider range of search engines, which also supports the findings of previous studies on the need for metacognitive regulation in the information search process. Thus, our study confirms and extends the findings of previous studies by showing that metacognitive instructions can significantly improve students' online search skills in computer science, which is an important contribution to educational practice.

Our study lacks the examination of plagiarism in student papers. At the same time, this factor is currently important due to the spread of technologies that make it possible to escape from plagiarism checking systems [90]. Further studies are likely to be aimed at integrating AI-technologies into metacognitive instructions to examine student papers for plagiarism. Besides, further research should probably take steps to minimize the influence of differences in search topics.

In addition, a longitudinal study by Bhattacharya [91] shows that students with more developed metacognitive skills search for information more efficiently. In this regard, a longitudinal study of students' search behavior over several semesters may be an interesting continuation of our study.

5- Conclusion

The purpose of our study was to evaluate the differential effect of metacognitive instructions on computer science students' online searches when writing review sections for academic papers. This study provides an empirical demonstration in this area and proves the results of other studies regarding the use of metacognitive instructions to improve online search efficiency and student progress. It also confirms that the use of meta-cognitive instructions induces planning, monitoring, and self-regulation of search behavior and generation of ideas and helps overcome mental stereotypes, which together form a metacognitive search strategy for students and increase the efficiency of the search. The planned information search is more effective than the trial-and-error search method. Self-regulation of search behavior is important due to the large volume of information available, its complex and heterogeneous structure, and the fact that search engine operation is becoming increasingly unclear to users. Based on the results of the experiments, it was concluded that the tutorial with the metacognitive instructions in the form of flowcharts and their thorough explanation is considered efficient to improve online search results of computer science students when writing review sections of course projects, final qualifying papers, etc. Besides, the experiment showed that the effectiveness of the tutorial decreases as the academic level of students rises. Thus, the research we have carried out answers the posed questions clearly and positively, namely, the metacognitive instructions improve the efficiency of student online searches for information and improve the quality of scientific source reviews. The results of the experiment support our hypothesis that adapted metacognitive instructions can be an effective approach to improve the information search efficiency of computer science students.

6- Declarations

6-1- Author Contributions

Conceptualization, S.S., A.A., and Y.K.; methodology, S.S.; software, Y.K.; validation, A.A., S.S., and Y.K.; formal analysis, S.S.; investigation, S.S. and A.A.; resources, A.A.; data curation, Y.K.; writing—original draft preparation, S.S. and Y.K.; writing—review and editing, S.S.; visualization, Y.K.; supervision, S.S.; project administration, A.A.; funding acquisition, A.A. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available in the article.

6-3- Funding

This work was carried out within the State assignment FSFN-2024-0059.

6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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